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(54) **ACCOMMODATIVE INTRAOCULAR LENS
AND METHOD OF IMPROVING
ACCOMMODATION**

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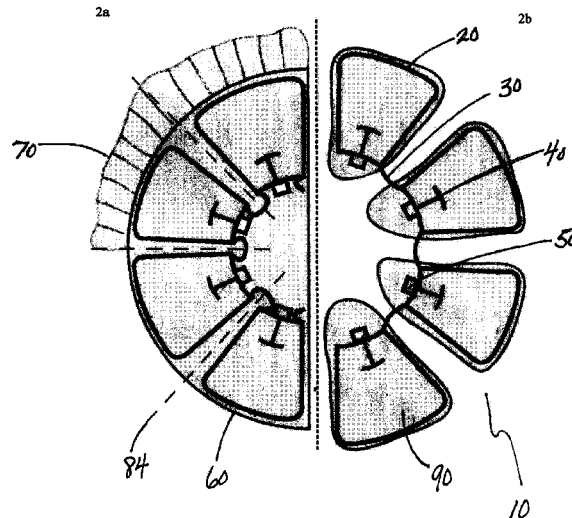
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(57) **ABSTRACT**

The present invention provides an accommodative intraocular lens (AIOL) system and method for improving accommodation with an intraocular lens. The method involves insertion into the capsular bag of a flexible optic holder comprising a plurality of haptics configured to allow the capsular bag to be sectioned at regular intervals following fusion of the capsular bag. The haptics of the optic holder are designed to allow maximum fusion of the anterior and posterior leaves of the capsular bag following placement of the optic holder in the capsular bag. Following introduction of the optic holder into the capsular bag, the natural or assisted process of fibrosis/fusion of the capsular bag occurs, thereby sealing and securely capturing the haptics within the capsular bag. Subsequently, several cuts are made in the fibrotic capsular bag at intervals between haptics, allowing the haptics to move independently, thereby effectively restoring some of the flexibility that the capsule possessed prior to fibrosis and restoring some of the zonular force on the capsule.

20 Claims, 13 Drawing Sheets



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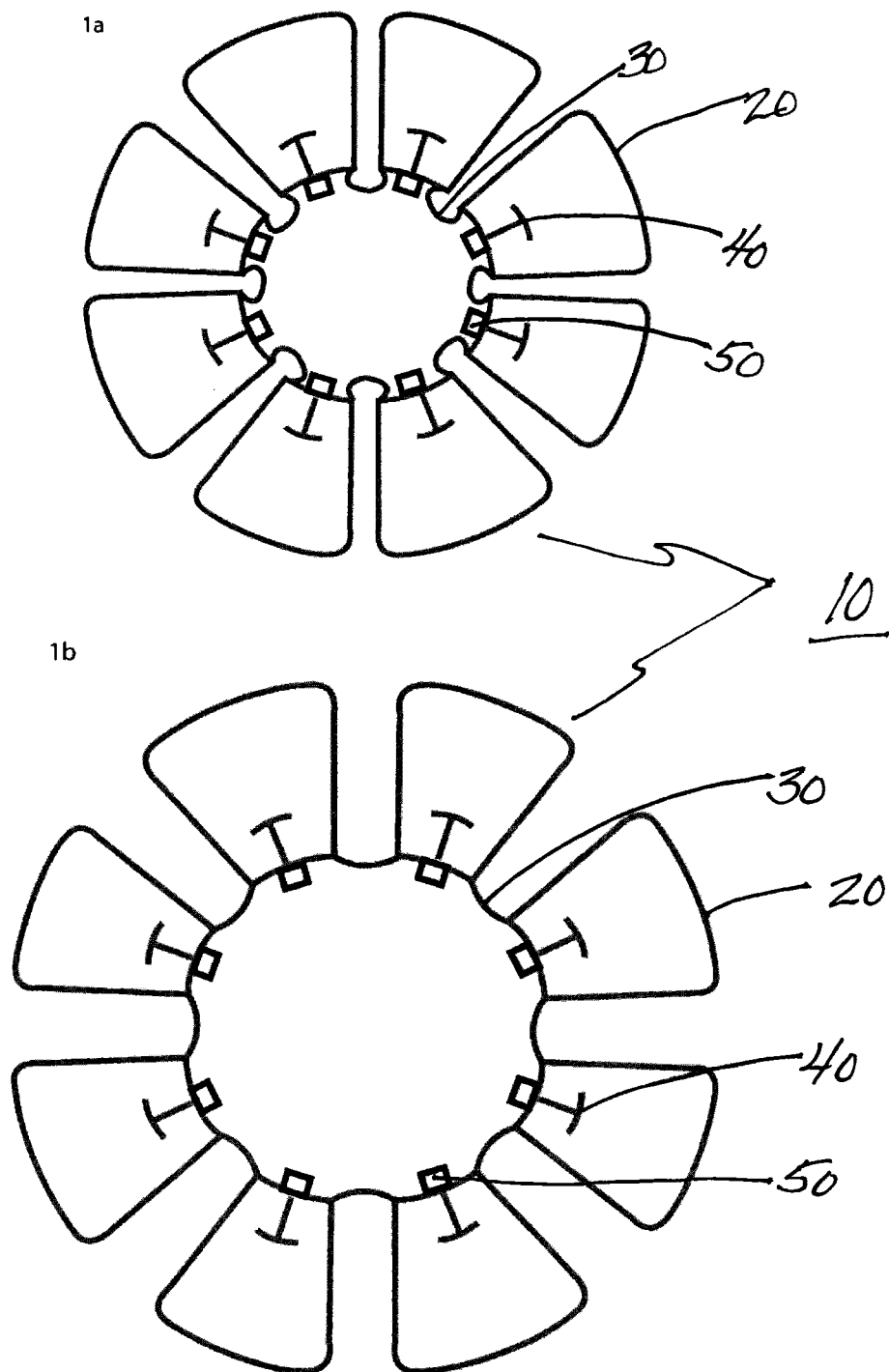


FIGURE 1

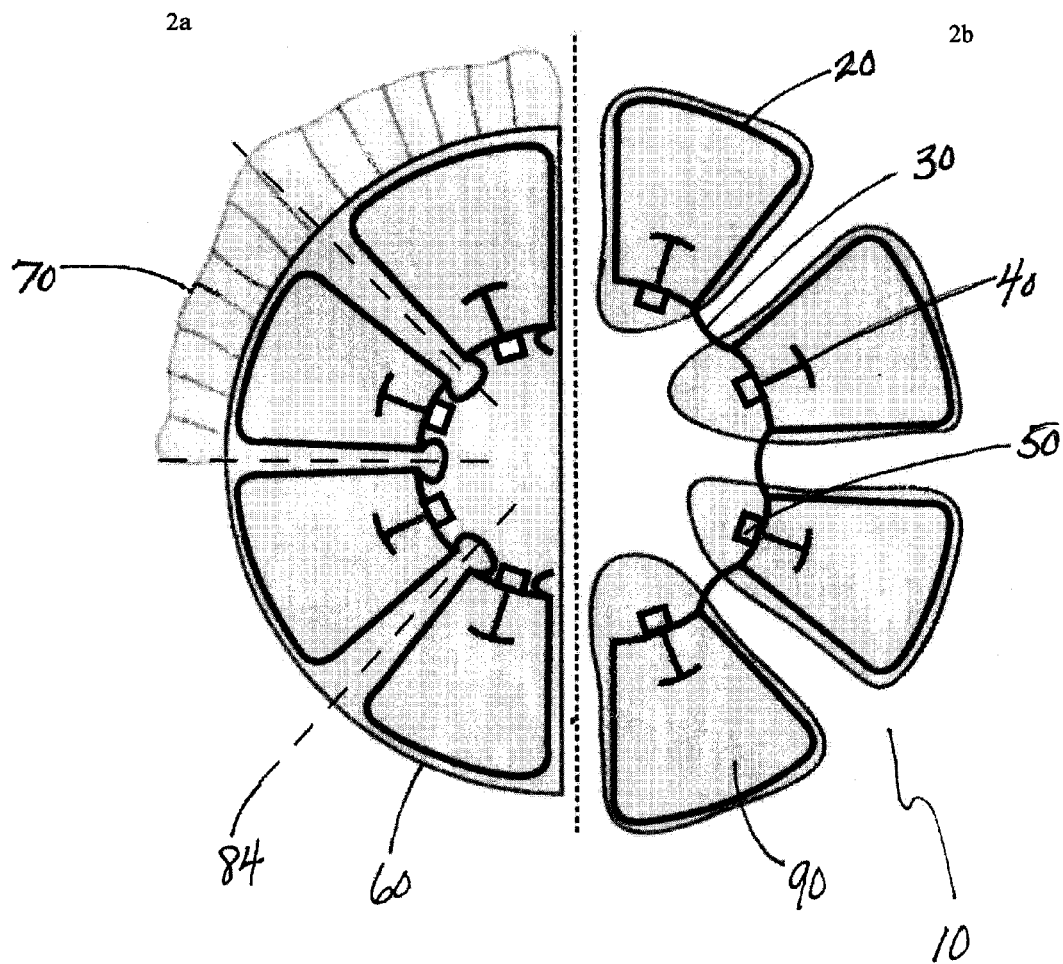


Figure 2

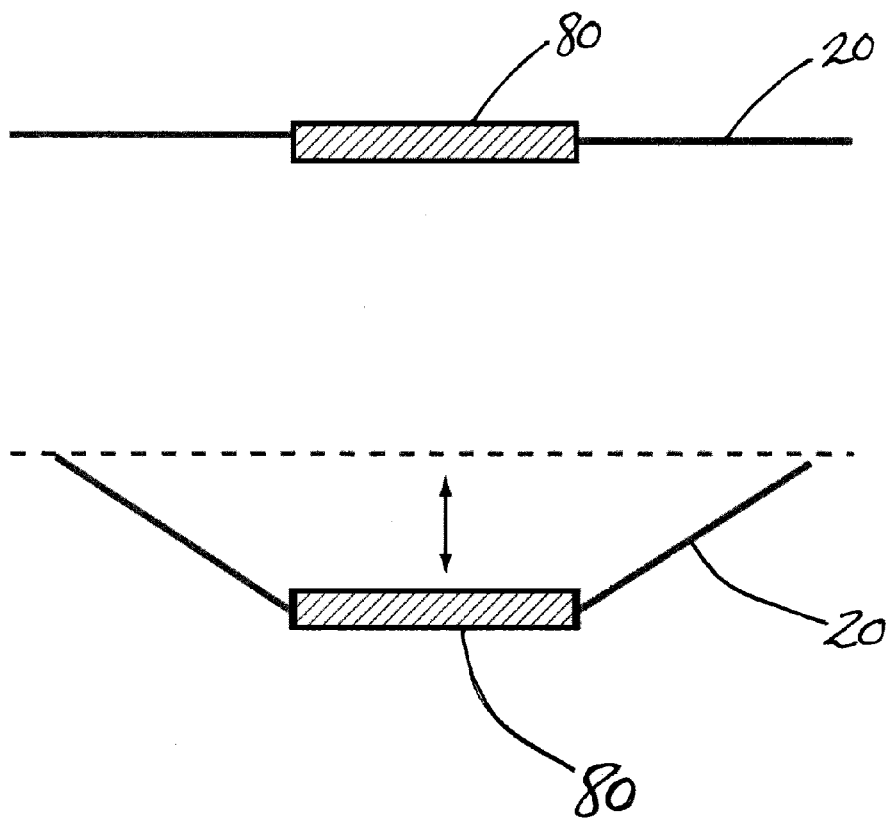


FIGURE 3

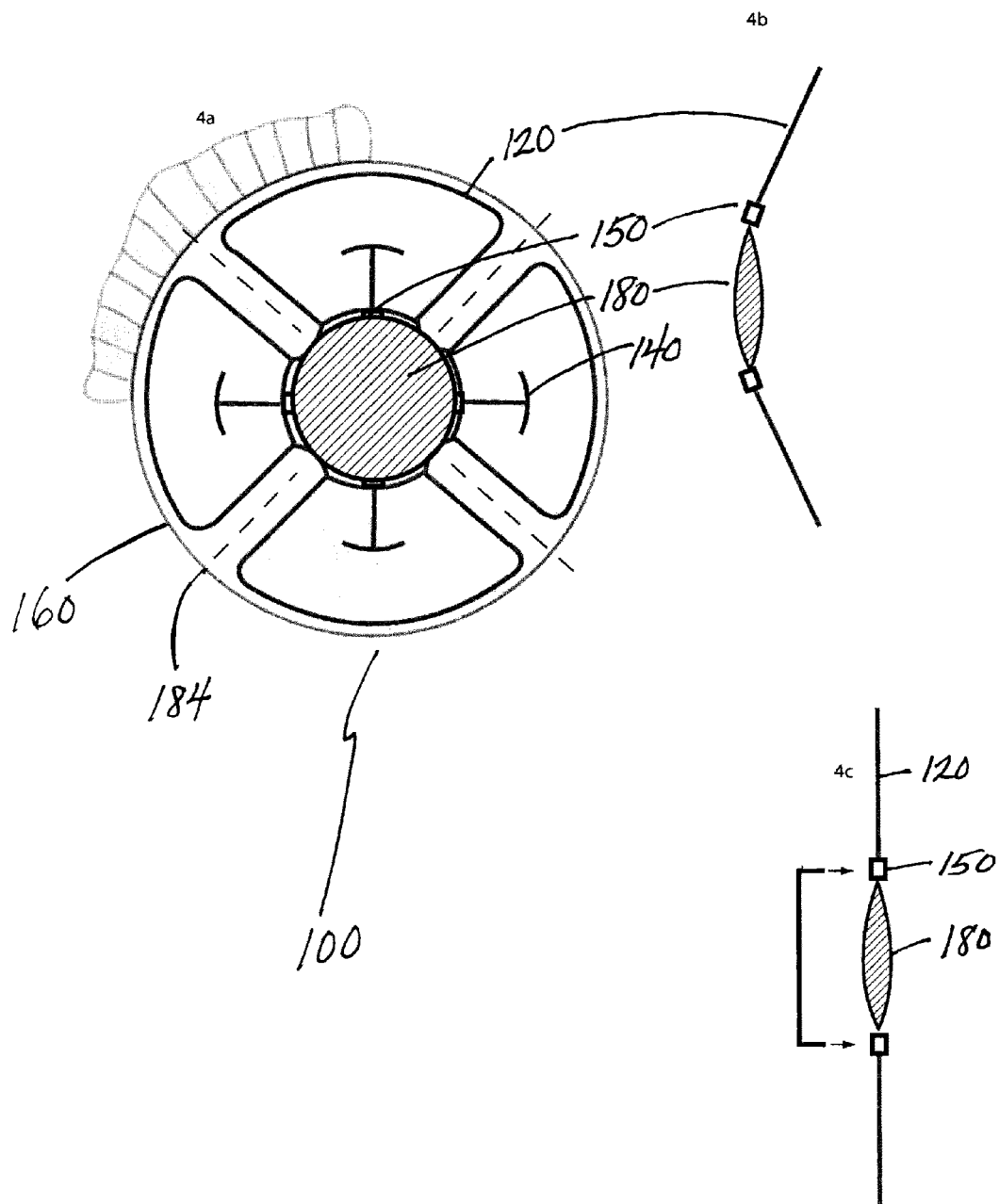


FIGURE 4

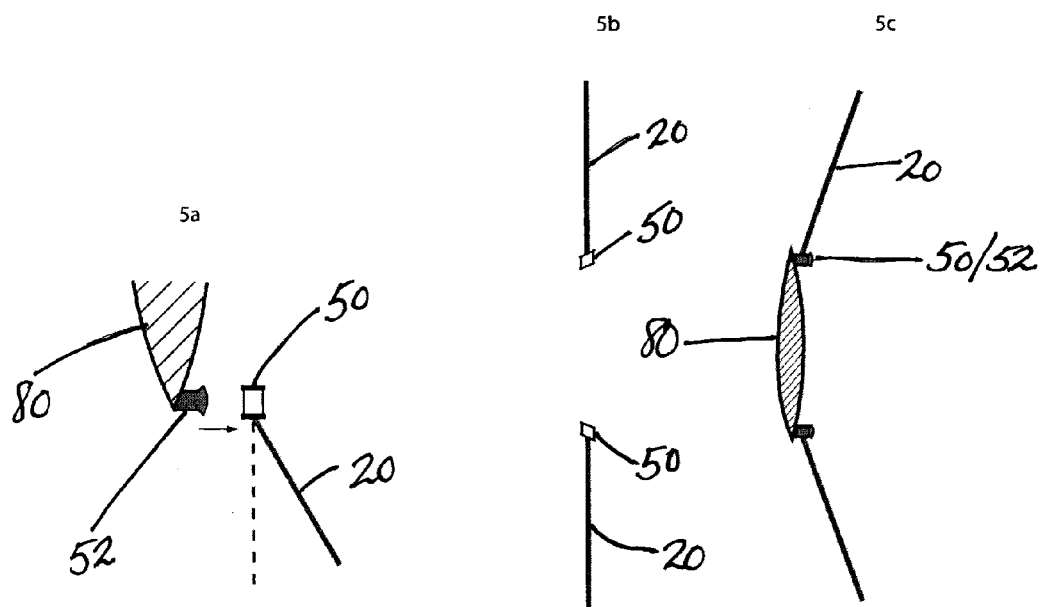


FIGURE 5

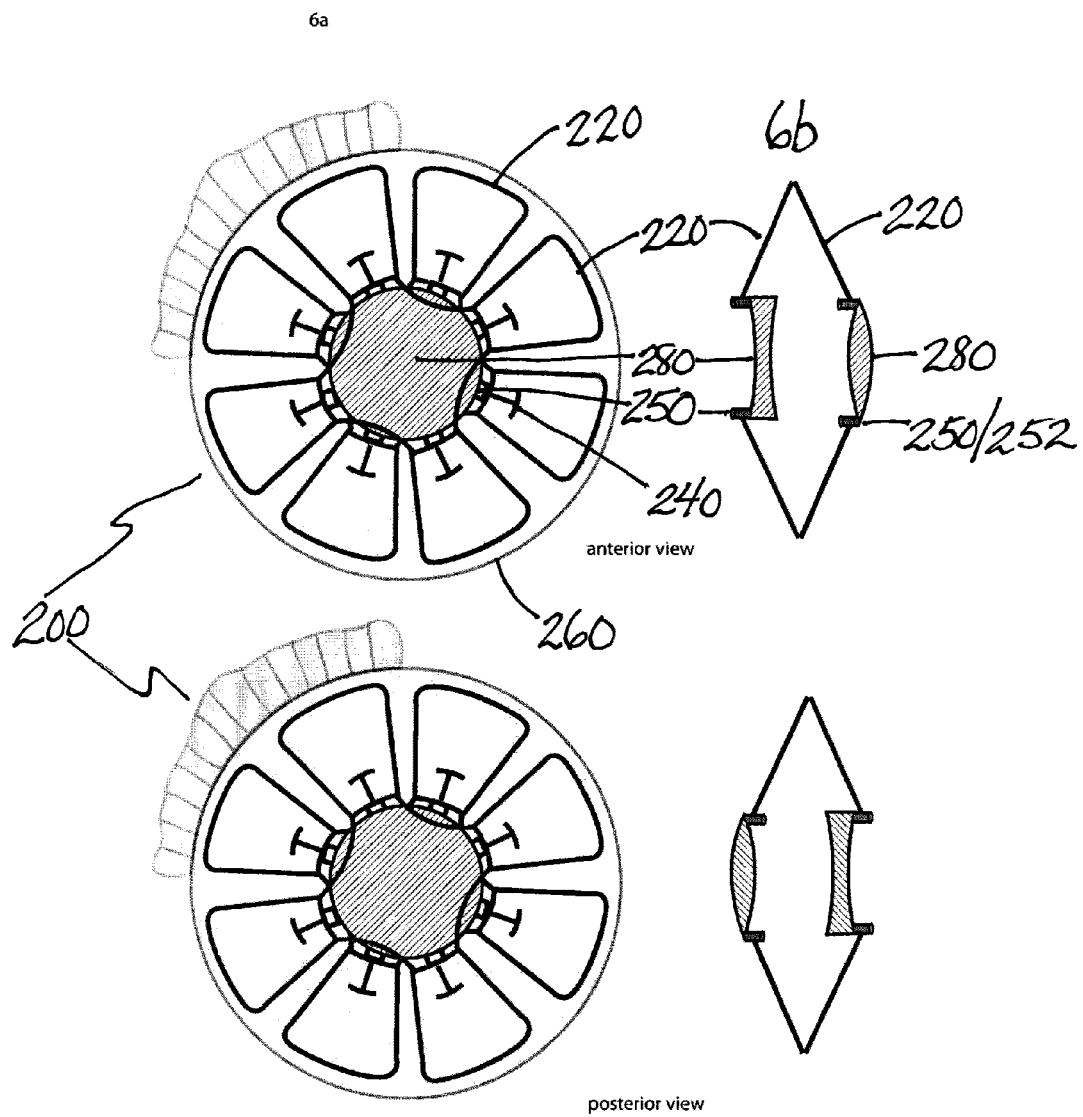


FIGURE 6

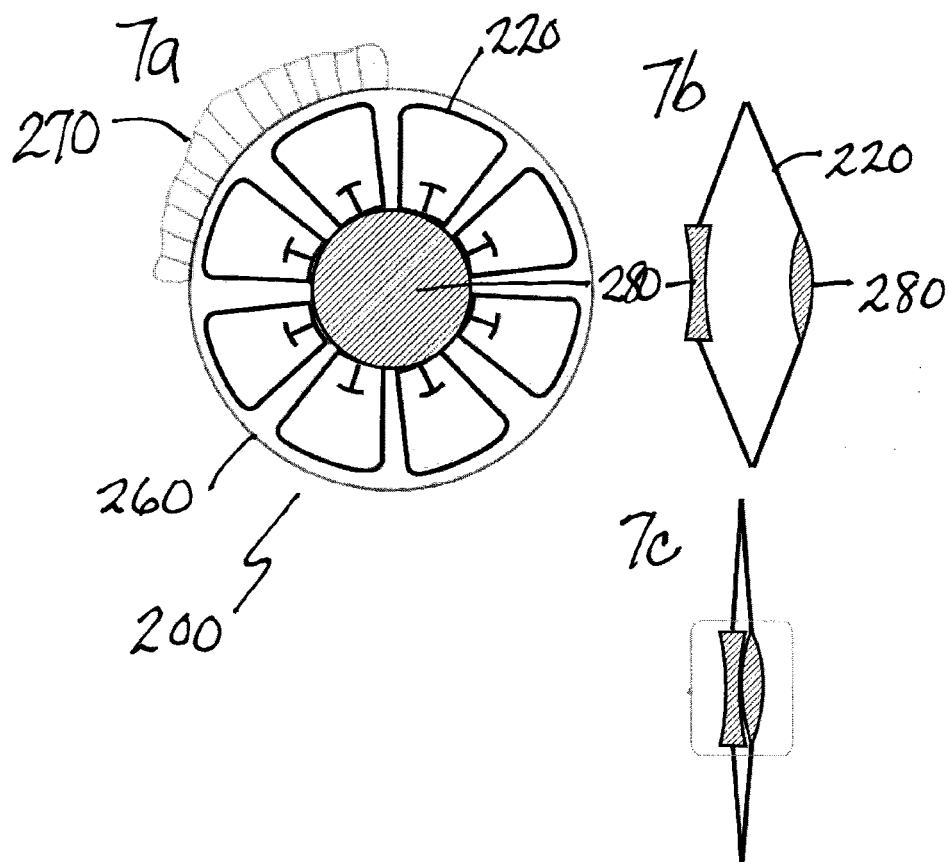


FIGURE 7

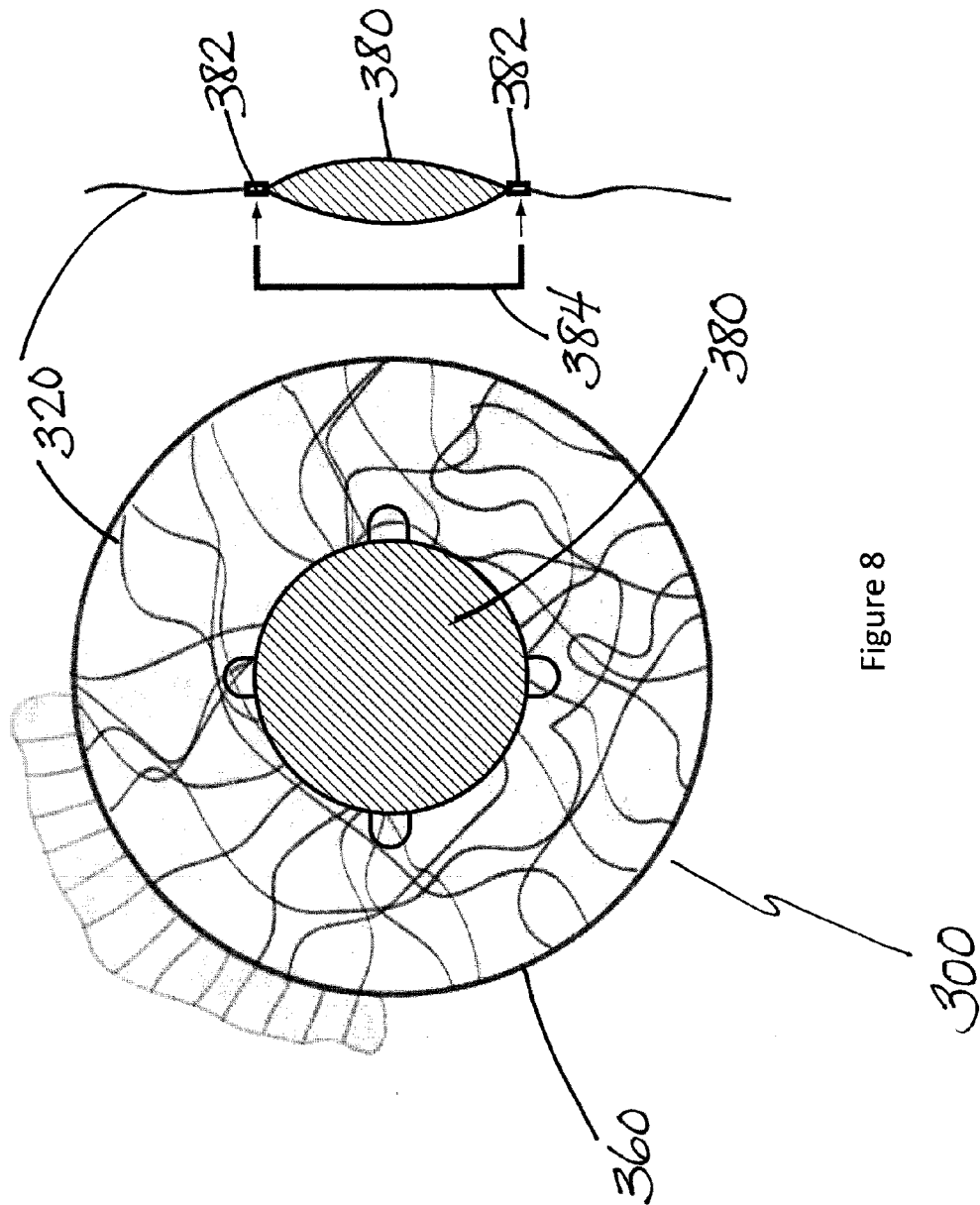


Figure 8

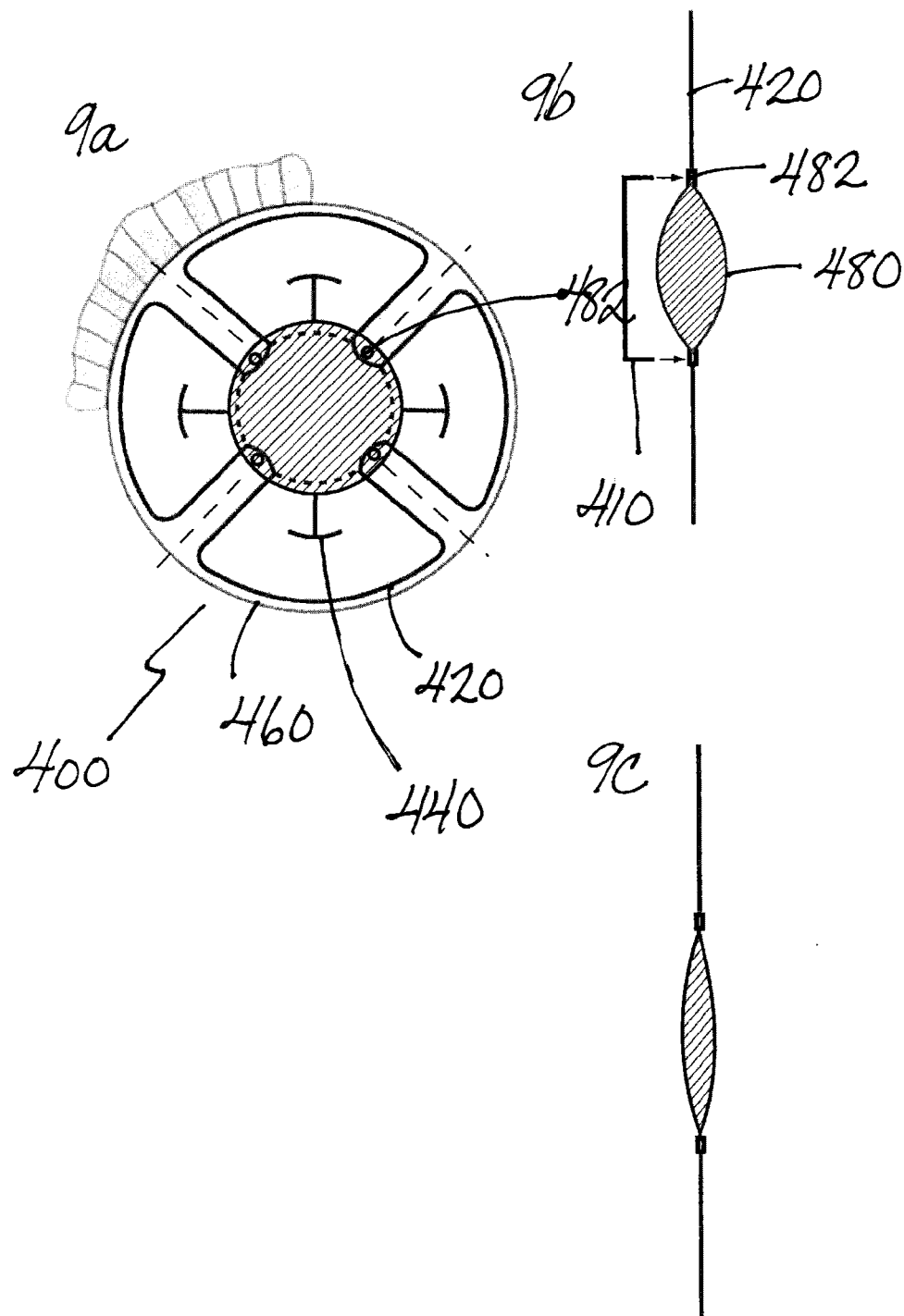


Figure 9

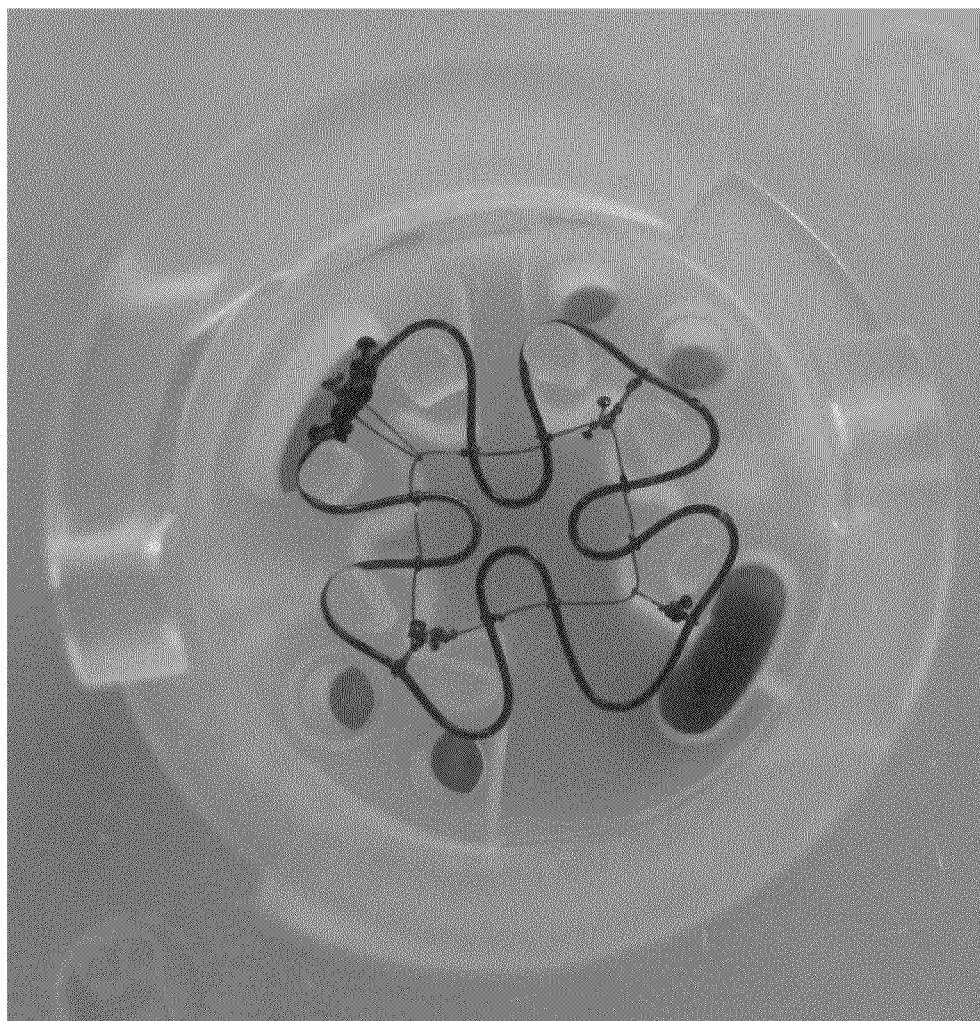


FIGURE 10

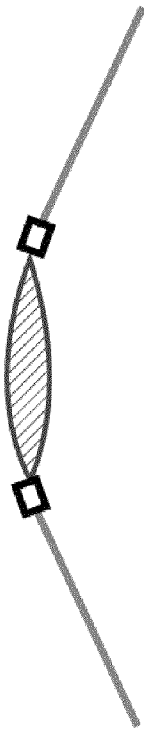
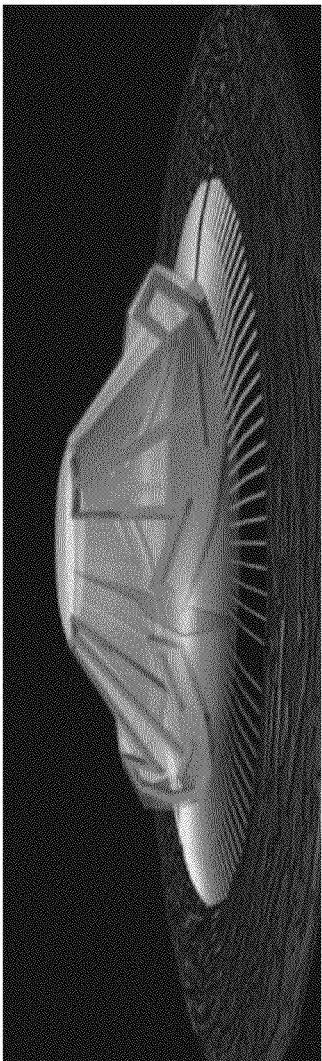


Figure 11

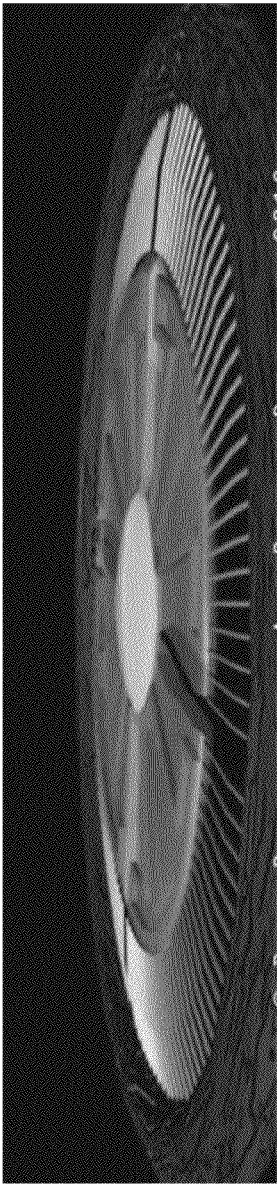


Figure 12

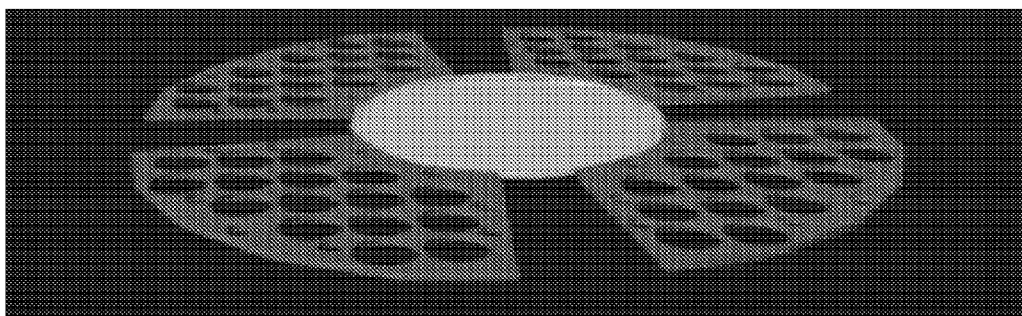
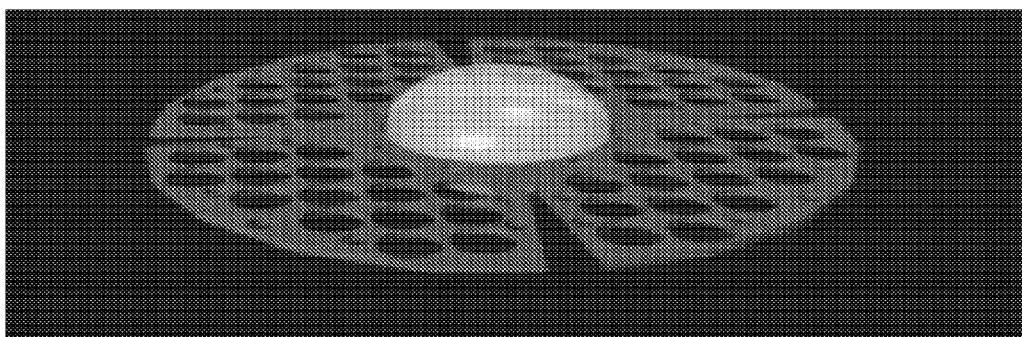


Figure 13

ACCOMMODATIVE INTRAOCULAR LENS AND METHOD OF IMPROVING ACCOMMODATION

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a U.S. Non-provisional application that claims the priority of U.S. provisional application No. 61/353,273, filed Jun. 10, 2010 and U.S. provisional application No. 61/368,862, filed Jul. 29, 2010. The contents of those applications are hereby incorporated by reference into the present disclosure in their entirety.

TECHNICAL FIELD

The present invention relates generally to intraocular lenses. More particularly, the present invention relates to accommodative, intraocular lens systems and methods for improving accommodation.

BACKGROUND INFORMATION

Under normal conditions, a healthy human eye focuses on near and distant objects by contraction and relaxation of the ciliary muscle thereby contracting and releasing the tension on the zonules in the eye. The contraction of the ciliary muscle releases zonular tension (accommodative state) and allows the lens to alter to a more globular or spherical resting shape. The relaxation of the ciliary muscle increases tension on zonules and elastic forces in the eye tissue overcome the inherent lens elasticity and result in stretching the lens equator and flattening the lens curvature (un-accommodative state).

In certain instances, for example when age-related opacification of the lens (cataract) interferes with vision, the natural crystalline lens of the eye needs to be removed. Generally, the natural lens is replaced with an artificial one, for example, an intraocular lens (IOL). Unfortunately, conventional IOLs, even those that profess to be accommodative, may be unable to provide sufficient spatial displacement of the lens along the optical axis to provide an adequate amount of accommodation for near vision.

In conventional extracapsular cataract surgery, the crystalline lens matrix is removed by phacoemulsification through a curvilinear capsulorhexis leaving intact the thin walls of the anterior and posterior capsules, together with zonular ligament connections to the ciliary body and ciliary muscles. An intraocular lens is then placed in the capsular bag, which collapses around the IOL.

Conventional single-optic accommodative intraocular lenses (AIOL) rely on the interaction of the ciliary muscle with the zonule and capsule to induce movement of the optic of the AIOL along its optical axis. Typically, the AIOL is secured within the capsular bag by two or more haptics that translate the radial stretching force exerted on the capsular bag by the zonules in an attempt to achieve the desired axial displacement of the optic.

However, during the post-implantation fibrotic healing process, the anterior capsule fuses with the posterior capsule to form a rigid capsular disc. Loss of elasticity of the capsular disc results and constrains the amount of movement that can be generated by the zonular force or elastic recoil of the intraocular lens and therefore, leads to a decrease in the amount of axial displacement of the lens that can be achieved.

Various lens systems have been designed to address this loss of accommodation. Passive-shift single-optic lenses, the only accommodative lens currently marketed, were designed

to move forward under ciliary muscle contraction. Accommodation in these systems, however, remains limited by the loss of elasticity in the post-fibrotic capsule. Even the limited amount of accommodative amplitudes generated by these lenses immediately after surgery is lost within the first few weeks or month after surgery as capsular fibrosis ensues.

Accommodative lens designs with single or multiple optic lens assemblies have been disclosed, for example, in U.S. Pat. Nos. and U.S. application nos. 2009/0125106, 2005/0209692, 2007/0156236, 2009/0005866, 2007/0005136, 2009/0248154. Dual optic lenses retain the problem of capsular fibrosis and loss of amplitude/movement even though they are reported to provide a significant amount of accommodation. However, concerns about possible long-term formation of interlenticular opacification remain.

More recently, a lens systems that employs an active-shift mechanism using repulsive mini-magnets as a means of making accommodation partially independent of the zonules and mechanical properties of the capsular bag was disclosed (see U.S. Pat. Application Nos. 2009/0204210 and 2007/0118216. Still other methods of achieving accommodation include introduction of a polymerizable fluid with a desired refractive index into the capsular bag (lens refilling). Extensive investigation into the feasibility of these methods is still needed.

U.S. Publication No. 2009/0234449 discloses an intraocular lens comprising an accommodating element that is in contact with a substantial portion of the zonular region; the accommodating element is positioned relative to optical element and configured to cooperate with the ciliary muscle, the zonules and/or the vitreous pressure in the eye to effect a shape change to the optical element. According to the '449 publication, prior art multiple lens systems can be cumbersome and also require an axial displacement unachievable with a collapsed capsular bag and resulting ineffective accommodative mechanisms.

The need remains therefore, for an intraocular lens system and an effective mechanism for improving the accommodative capacity of an IOL following implantation. None of the current lens concepts take into account that the devitalized capsular bag after cataract surgery changes its physical properties from an elastic sphere to a contracted rigid disc.

SUMMARY OF THE INVENTION

Briefly, the present invention provides an intraocular lens system and method for improving accommodation that remedies the loss of axial and centrifugal movement caused by shrinkage and loss of flexibility of the capsular bag following implantation of conventional lens systems. A lens system of the present invention includes a flexible optic holder comprising a plurality of zonular capture haptics, in particular, regularly-spaced haptics that are adapted to allow or facilitate fusion of the capsular bag following placement of the optic holder within the capsular bag and ultimately to permit the sectioning of the fused capsular disc. During fusion, each haptic becomes permanently entrapped in its respective capsular disc section; sectioning frees adjacent haptics from each other; each haptic can, therefore, move independently in response to ciliary muscle and zonular forces on the capsule. The action of the zonular capture haptics can be translated to different types of optics suited to provide accommodative amplitude. The restored elasticity of the present accommodative IOL system, which allows the optic to return to a resting state when zonular tension is released, is provided by angulated haptics which straighten under zonular tension, by the elasticity of the optic or a combination of both.

The novel optic holder of the invention is implanted in two stages: first, the optic holder (which may or may not include an integral optic at this stage) is implanted and sufficient time is allowed for fusion of the anterior and posterior leaves of the capsular bag around the implanted device. In a second stage, the fused and fibrosed capsular bag is sectioned at regular intervals determined by spaces between the haptics of the optic holder, to reduce its rigidity, thereby restoring some of the movement lost during fusion of the capsule, fibrosis and formation of the capsular disc. The force of the zonules is uniformly transmitted to the lens via the entrapped haptics.

Unless it is already an integral part of the zonular capture haptic, the optic of the lens system may be inserted into the haptic during a second stage of the procedure. Any mechanical means or chemically-induced tensioning or positioning of the haptic/optic complex, which may have been employed to control the accommodative state of the haptic-lens complex during the fusion and contraction of the healing capsular bag would be removed at this juncture.

In one aspect, therefore, the present invention relates to a method for improving accommodation with an intraocular lens (IOL) system, the method comprising introducing a flexible optic holder with zonular capture haptics into the capsular bag of an eye of a subject and allowing a period of time sufficient for fibrosis of the capsule to occur so that the zonular capture haptics are captured within the fused capsule. During this time the eye may be maintained in either an unaccommodative or accommodative state by administration of an agent to inhibit or induce accommodation, for example, atropine or pilocarpine, respectively. Alternatively, mechanical means may be used to retain the capsule in a flattened and maximally (unaccommodated) or minimally (accommodated) expanded configuration. Apposition of the anterior and posterior leaves of the capsule to facilitate fusion may also be achieved by introduction of an air bubble anterior to the capsular bag. Other mechanical, chemical or biological means may be utilized to enhance the adhesion of the anterior and posterior capsule.

In a second stage, cuts are made in the fibrotic capsular disc at sectioning intervals between the zonular capture haptics of the optic holder. In some embodiments, during this second procedure, the optic is inserted into the holder.

In a related aspect, the invention relates to a flexible optic holder comprising an arrangement of zonular capture haptics that permits 1) complete integration of the haptics during fusion of the capsule to form a capsular disc and 2) sectioning of the fused capsular disc. The optic holder comprises a plurality of hollow closed-loop or fenestrated haptics that extend outwardly from the center of the optic holder to define a disc that is roughly coextensive with the capsular disc and provides a template for sectioning of the disc following fusion. The optic holder of the invention is configured to provide support for an optic, to facilitate fusion and fibrosis of the capsular disc, to allow sectioning of the fused capsular disc and to uniformly translate force from the zonules to the optic.

In one aspect, the invention relates to an intraocular lens system for implantation in a capsular bag of an eye, comprising 1) a flexible optic holder comprising a plurality of haptics that extend outwardly from the center of the optic holder with sectioning regions therebetween where the haptics define a disc that is roughly coextensive with the capsular disc; and 2) an optic adapted to fit into the optic holder. The intraocular lens system is configured to be coextensive with the capsular bag when placed therein and to become fixed within the capsular bag once fusion of the capsular bag has occurred.

The optic holder comprises a plurality of regularly spaced haptics, for example, from 3 to 120 haptics. In an alternate embodiment, the flexible optic holder comprises a single haptic with a fenestrated structure or of a surgical mesh or similar woven material with holes sufficiently large to allow contact and fusion of the anterior and posterior capsule through the fenestrae or holes. The haptics are spaced at regular intervals, with the space between adjacent members defining a sectioning region.

These and other objects, features and advantages of this invention will become apparent from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1a and 1b are illustrations of one embodiment of a flexible optic holder of the invention; FIG. 1b shows the optic holder in its expanded form.

FIGS. 2a and 2b show one embodiment of the invention inside the capsule of an eye prior to (2a) and following sectioning of the capsular bag (2b).

FIG. 3 is a schematic showing the position of the optic in the unaccommodated (top) and accommodated (bottom) states. During accommodation, the optic moves anteriorly (shown as downward); the dotted line indicates the position to which the optic returns when in the unaccommodated position.

FIG. 4a shows an alternate embodiment of the optic holder in the capsule, prior to sectioning, in which an optic has been secured. FIG. 4b shows the position of the haptics relative to the optic during accommodation; FIG. 4c shows the relative positions of the haptics and the optic under zonular tension (un-accommodative state). A staple-like retainer, for stabilizing the optic during fusion is also shown.

FIG. 5a shows an embodiment in which a snap-like fastener is used as optic attachment means for securing optic in optic holder; 5b shows the relative positions of the haptics and optic attachment means when the optic holder is fused within the capsule; 5c shows the relative positions of the haptics and optic during accommodation following sectioning of the capsular disc.

FIG. 6a shows anterior and posterior views of a dual-optic system in which two optic holders (black and gray) are used; FIG. 6b shows the position of the two optics during accommodation.

FIG. 7a shows an embodiment of the dual-optic system in which optics are an integral part of the optic holders; the positions of the two optics during accommodation (7b), and unaccommodation (7c) are shown.

FIG. 8 is an embodiment of an optic holder with a single dough-nut shaped haptic made of a woven or mesh-like material that can be cut, for example, with surgical scissors. A side view of the optic/optic holder is shown with a retainer, mechanical means for maintaining the minimum diameter (maximum contraction) of the capsular bag during fusion.

FIG. 9a shows an embodiment of the optic holder with an integrated flexible optic that approximates the natural lens; in the absence of zonular tension (accommodation), the optic is more spherical (9b) than when it is in the unaccommodated state (9c).

FIG. 10 is a photograph of an experimental model of a haptic design of the invention.

FIG. 11 includes a computer generated image and a schematic to illustrate the relative positions during accommodat-

tion of the haptics and a non-flexible optic using the optic holder of the present invention after the fused capsular bag has been sectioned.

FIG. 12 includes a computer generated image and a schematic to illustrate the relative positions of the haptics and non-flexible optic in the unaccommodative state using the optic holder of the invention.

FIG. 13 includes a computer generated image to illustrate radial movement of the haptics when optic holder of the invention is used with a flexible (stretchable) optic.

DETAILED DESCRIPTION OF THE INVENTION

All patent applications, patents and other references cited herein are hereby incorporated by reference in their entirety into the present disclosure.

In ophthalmology, the term “haptic” refers to a support structure that extends out from an optic element of an intraocular lens, for holding the lens in place within the capsular bag of the eye. For purposes of the present invention, “haptics” are sometimes referred to as “zonular capature haptics” and refer to structures or material that not only assist with placement and centration of the lens within the capsule, but are frame-like or fenestrated structures, which permit or facilitate fusion of the anterior and posterior capsules following removal of the natural lens and placement of the artificial lens so that the haptics become securely entrapped within the fused capsule. The haptics define individual “sections” of the capsule which can be separated after fusion has occurred by making radial cuts in the capsule, specifically, beginning near the center and extending out to the equator of the capsule. Following sectioning, each haptic is contained within a separate section of the capsule. The haptics of the optic holder of the invention have features which specifically enable it to become integrated into the fused capsule during fibrosis and then uniformly translate the movement that results from contraction and relaxation of the ciliary body to the optic.

As used herein, the term “retainer” refers to a removable rigid device that is utilized to maintain the IOL system in controlled state of accommodation during the healing, fusion period and is removed once fusion is complete. For example, IOL systems, which rely on angulated haptics as a mechanism of accommodation, would be maintained in an un-accommodated state during fusion of the capsular bag; keeping the optic holder in a flat planar configuration allows maximum contact between the anterior and posterior capsule to enhance fusion and eliminate distortion of the capsular bag. In a single optic system, for example, the retainer may consist of a rigid rod with right angle extension inserting into each diametrically opposed pair of haptics. In a double optic system, a simple suture ligation may be sufficient to maintain the two optics in apposition to each other, reducing the angle of the posterior and anterior haptics to a flat planar configuration. For flexible, prefilled or fillable pouches, the restraining device may be utilized to maintain the IOL system in an accommodated position to encourage the contraction of the capsular bag to a minimum diameter, thereby maximizing the ability of the IOL system to stretch during relaxation of accommodation after the sectioning of the capsular bag.

Such a device may be mechanical or chemical, and may be released by chemical, mechanical, laser or optical means.

As used herein, the term “fenestrated” indicates the presence of an opening or openings that allows for contact between the anterior and posterior capsule thereby facilitating fusion of the capsule through the opening(s).

Conventional accommodating lenses typically involve converting diametral movements of the ciliary muscle into

forward and backward movement of an optic portion of the IOL relative to the retina. For example, the only currently marketed accommodating IOL is a rigid, single optic IOL designed to rely on a forward translation of the optic to produce an increase in optical power of the eye. Movement of the IOL is produced by ciliary muscle contraction, capsular bag elasticity and/or suggested changes in vitreous cavity pressure to create an optical change in the eye.

However, implantation of the IOL into the capsule is followed by a natural physiological process not unlike applying a shrink-wrap film, in which the anterior and posterior capsular bag surfaces fuse around the haptics and seal the IOL within the fibrotic capsule. Furthermore, the fusing capsule undergoes fibrosis. During fibrosis the bag undergoes further contraction and loss of elasticity. As a result of this process, the IOL is immobilized within the fibrosed capsular disc and movement of the optic along the optical axis is extremely limited.

The present invention is directed to an optic holder having a haptic system designed to restore capsular flexibility lost during fusion and fibrosis. This haptic system allows an implanted lens to transition more effectively between the accommodated and unaccommodated states, that is, in a fashion similar to the natural lens in response to forces applied to the capsule by the ciliary muscle and zonules. It achieves this by employing a haptic system that is flexible and becomes securely integrated into the fused capsular disc and allows for the capsular disc to be cut into sections, which has the effect of reducing the rigidity of the fused capsular disc and allows the optic holder to expand.

The present invention, therefore, is directed to a flexible optic holder comprising a plurality of haptics arranged in a circle and extending outwardly from a center portion of the optic holder (see FIGS. 1a and 1b). In addition to providing centration of the optic within the capsule like the haptics in conventional intraocular lenses, the haptic system of the optic holder of the present invention provide closed-loop, frame-like structures that allow contact between the anterior and posterior capsules so that the process of capsular fusion and fibrosis are not impeded, thereby creating a skeletal support for the capsular disc. The natural post-phacoemulsification healing process is important for integration of the haptics into the capsular disc. Furthermore, the haptics are regularly arranged around the optic holder ring with a space between adjacent haptics to permit the fused capsular disc to be cut at regular intervals.

The haptics of the optic holder of the invention may be rigid or semi-rigid structures and may be made from a generally continuous element or a single continuous element of varying widths or thicknesses as long as the ability of the anterior and posterior capsules to securely fuse through the haptic is preserved. Haptics are made of a suitable nonabsorbable surgical material such as surgical wire, suture or the like. In one embodiment, haptics are constructed of polypropylene suture material, such as Prolene® (Ethicon, Somerville N.J.) The haptics of the optic holder may optionally include additional structures within the haptic frame, such as cross bars or anchors (for example, as shown in FIG. 1), to reinforce the haptic within the capsule following fusion. Anchors may be T-shaped, or a grid with cross-members that cross the length and/or width of the haptic.

The present invention also provides a two-stage process for inserting into an eye the intraocular lens system of the invention to achieve an improved level of accommodation. In one embodiment, evacuation of the capsular bag is followed by placement within the capsular bag of an optic holder that comprises one or more haptics that define a capsule-reinforce-

ing disc and which will ultimately receive the optic of the IOL system. Implantation of the haptic is followed by a healing interval, that is, a period of time sufficient to allow the anterior and posterior capsular bag surfaces to fuse together through and around the haptics of the optic holder thereby sealing the haptics within the fibrotic capsule. In one embodiment of the method, fusion of the capsular bag around the haptic occurs under conditions in which ciliary body movement is restricted, for example, by atropine-induced cycloplegia or pilocarpine-induced accommodation; paralysis of accommodation movement optimizes capsular disc size, and enhances fibrosis of the capsule. Alternatively, mechanical means for maintaining the capsule in the unaccommodative or accommodative state, for example a retainer, may be employed to achieve the desired capsular disc size. The absence of an accommodating optic during the phase of capsular fusion allows the optic holder to be free of mechanical strain and capsular bag distortion during the fusion and fibrosis period.

During the second stage the capsular disc and incorporated haptics are sectioned to reduce the rigidity of the capsular bag so that the force exerted by the zonules can more effectively be transmitted to the capsule and permit movement of the optic along its optical axis and in the case of flexible optics, accommodative and unaccommodative movement caused by contraction of the ciliary muscle and/or zonular tension. Cuts are made radially and at regular intervals between the haptics, (see FIG. 3) extending from the visual axis to the equator of the capsular disc. The accommodating optic may be inserted into the ring of the optic holder at the time of sectioning, either before or after sectioning. The optic contains means for securing the optic into the lens holder, for example a circumferential releasable connecting rib or series of releasable connecting tabs, pins, plugs or the like that snap into a corresponding receptacle: a groove, notch or hole on the inner edge of the haptic.

The intraocular lens system of the invention comprises a rigid or flexible optic, single lens or multiple lenses, or fillable or pre-filled, and in one embodiment, an accommodating optic and optic holder are inserted as a single unit at the time of initial cataract surgery. Such an integrated intraocular lens system may include a restricting device to mechanically or chemically maintain the system in a specific state of accommodation during the fusion and fibrosis of the capsular disc, for example a maximally accommodated optic and pilocarpine-induced pharmacologic accommodation during the entire duration of capsular fibrosis and fusion. This eliminates mechanical strain or movement or distortion of the capsular bag during the fusion/fibrosis phase after the first stage procedure, optimizing the size of the fibrotic capsular disc, sealing of the haptic members in the capsular disc and resting tension on the zonules.

During the second stage, radial cuts are made in the capsular disc, between the haptics, and extending from the visual axis to the outer edge of the capsular disc. This releases the restraining effect of fibrosis on the now segmented, capsular bag. An optic restraining device, if employed, is also removed at this time allowing the accommodating optic to respond to the zonular tension transmitted by the haptics during relaxation of accommodation, or to return to its resting accommodating state during contraction of ciliary body and relaxation of the zonules.

The method of the present invention for the implantation of an intraocular lens, therefore, includes making a plurality of regularly-spaced radial cuts around the capsule/haptics, extending from the visual axis to the edge of the capsular bag. Sectioning alters the rigidity of the capsule following capsular fibrosis/fusion so that the tension and relaxation of the

zonules is more effectively translated to the capsule thereby enhancing spatial displacement of the optical element.

Uniform and complete natural, therapeutically-assisted or -enhanced fusion of the capsule around the haptic prior to optic placement ensures uniformity of sectioning essential to centration and stability of the optic once it is inserted.

Following insertion, the patient undergoes a recovery period of one to six weeks, preferably two to three weeks, for complete fibrosis of the capsule to occur. A second surgical procedure is performed to restore "elasticity" to the capsule by making radial incisions in the capsule at regular intervals forming roughly triangular or trapezoidal sections, each of which contains one of the haptics of the optic holder.

By "sectioning" the capsular disc, greater movement of the optic along the optical axis is achieved. Each haptic-reinforced section of the sectioned disc is generally separate from the others, held together by the inter-haptic connectors of the lens holder and the optic, when it is positioned within the optic holder. As a result of the sectioning, however, the force generated by the zonules is more effectively transmitted to the optic.

It is hypothesized that a 1 mm change in capsular bag diameter results in 2 mm anterior/posterior optic movement. A 12 mm capsular bag under zonular tension, (i.e. unaccommodated) collapsing to 11 mm in diameter as a result of the AIOL tension will result in a 2 mm anterior displacement during accommodation. Expected ranges of total accommodation with rigid single and double optics and flexible deformable optics are shown in Table 1.

TABLE 1

	Single Optic	Dual Optic	Flexible Optic
Actual accommodation	2D	6D	4-7D
Pseudo accommodation	1.5-2D	1.5-2D	1.5-2D
Total accommodation	3.5-4D	7.5-8D	4.5-9D

Intraocular Lens System

The intraocular lens system of the invention comprises 1) a flexible optic holder specifically adapted to permit fusion of the capsule and sectioning of the capsular disc once fusion is complete and 2) an optic. The optic holder comprises a plurality of haptics adapted to receive and secure the optic(s). The optic holder supports the optic around its equator and couples the optic to the capsular bag of the eye. Following extraction of the natural lens and placement of the flexible optic holder of the invention into the capsular bag, the natural healing process causes the optic holder to become entrapped, "capturing" the capsule, when the anterior and posterior leaves of the capsular bag fuse together. Subsequently, radial cuts to the capsule allow the sections of the fused capsule and the captured haptics to move independently of the others in response to zonular tension.

Optic Holder with Zonular Capture Haptics

The intraocular lens of the invention comprises a optic holder with zonular capture haptics, that is, haptics, which by their closed-loop design, allow maximal fusion of the anterior and posterior capsule through the haptics and permit the capsule to be sectioned following fusion, so that, in response to tension by the zonules, each haptic is able to move radially away from the center of the optic holder and then return to the initial position when zonular tension is released. The haptics

become fused within the capsular bag and enables the capsule to be sectioned into a plurality of capsular "sections." The haptics provide fixation, centration and stability of the optic (s) within the eye and provide a skeletal support for the capsular bag so that its rigidity can be reduced by cutting it into sections.

One embodiment of an optic holder of the present invention is shown in FIG. 1. Optic holder 10 comprises a plurality of haptics 20 extending outwardly from the center of optic holder 10. The arrangement of haptics 20 generally defines a ring that receives an optic 80, and haptics 20 further comprise optic attachment means 50/52 to hold the optic 80 securely in place. In this embodiment, haptics 20 are roughly trapezoidal in shape. Adjacent haptics 20 are connected via an inter-haptic loop or connector 30 of flexible material so that the inner edges of haptics 20 form a continuous ring to which the optic is ultimately attached.

In some embodiments, optic holder 10 is flexible (FIG. 1b). The haptics 20 are spaced apart at regular intervals to generally form a disc that is roughly coextensive in size with the capsular bag and retains the circular shape of the fused capsular disc. Following placement of an optic holder of the invention into the capsular bag, the capsule will shrink and fuse around the optic holder (much like shrink-wrap). As shown in FIG. 2b, once fusion of the capsule is complete, cuts are made between the haptics of the optic holder. This allows the sections to move somewhat independently of each other.

FIG. 2a shows an embodiment of an optic holder of the invention within the unsectioned capsular bag (shaded area). Following sectioning between haptics (FIG. 2b), the optic experiences improved freedom of movement, compared to the unsectioned capsule in response to zonular tension.

In FIG. 3, the positions of the haptics and optic of any intraocular lens, including conventional intraocular lenses, once the capsule has fused and become fibrosed are shown in the upper panel. The bottom panel shows anterior movement of the optic (shown as downward movement) made possible by sectioning the fused capsule using the optic holder of the present invention.

FIG. 4a shows an embodiment of an optic holder 100 in which an optic 180 has been secured prior to sectioning of the capsular bag; sectioning lines 184 are indicated. The position of the optic 180 and haptics 120 during accommodation (4b) and the unaccommodative state (4c) are shown.

FIG. 5 shows an embodiment of optic attachment means 52/50, for example, a pin 52 and receptacle 50 snap-like fastener, by which optic 80 is secured in optic holder. Because the haptics are angulated, without any other force in play, insertion of the optic into the holder forces the haptic into a roughly 30° angle with the optic.

In one embodiment (see FIGS. 6 and 7), a pair of anteriorly- and posteriorly-angled optic holders are used in an alternating arrangement or configuration. The anterior haptic will receive an anterior optic, while the posterior one will receive a posterior optic. In the dual-optic system, during accommodation, zonular tension is released and the haptic system returns to its resting state of maximum angulation of the optic attachment means causing the two lenses to move axially away from each other, thereby providing increased accommodative amplitude.

When tension is applied to the optic holder during relaxation of ciliary body, the haptics straighten thereby causing an axial displacement of the optics towards each other (as shown in FIG. 7c). With a dual-optic system, maintenance of the appositional relationship of anterior and posterior optics is important to ensure uniform fusion of the capsule. This may

be achieved mechanically or through the use of therapeutic agents that induce unaccommodation.

Referring to FIG. 8, in one embodiment, the optic holder 300 comprises an optic 380 or optic holding member at its center and a single doughnut-shaped haptic 320 extends outwardly from the optic 380 and is made of a woven material or mesh or fenestrated material that 1) permits fusion of the capsular bag and 2) can be sectioned or cut. Radial sectioning lines (not shown) may be indicated on the capsule-capture haptic and small holes near the optic/optic holding member provided for starting the cut.

FIG. 9 shows an embodiment in which haptics 420 and optic 480 comprise a single unit, with a flexible optic 480, or fillable or prefilled optic pouch attached directly to the haptics 420. Such an optic has a predetermined dioptric power in its resting state (9b). The inherent optic elasticity allows stretching of the optic equator and flattening of the lens curvature in the un-accommodative state (9c) and return to a more spherical shape (9b) during accommodation when zonular tension is released.

Flexible optics, fillable or prefilled optic pouches are known in the art and can be integrated or adapted for use with the optic holder of the invention. The adaptation of any elastic optic embodiments to a zonular capture optic holder would enable the optic to change shape and accommodate.

In some embodiments, the haptics further comprise an anchor or other support structure for promoting fusion/fibrosis of the capsular bag and integration of the haptic within the capsular bag. The anchor may be any shape, for example, T-shaped, or size which will have the effect of securing and reinforcing the haptic within the capsular bag.

Implantation of the Optic Holder

In an initial procedure, the optic holder is placed in the capsular bag of the eye, and the anterior and posterior leaves of the capsular bag are allowed to fuse together securing the optic holder within the fused capsular bag or disc. Uniform healing of capsule around optic holder ensures centration of the optic once it is placed in optic holder.

In a second procedure, a number of cuts are made in the capsular disc between the haptics of the optic holder. The cuts extend from the visual axis to the outer edge of the capsular disc. Additionally, the posterior zonules may become stiff further limiting anterior/posterior movement. In some situations, it may be desirable to cut the posterior zonules.

In one embodiment, the optic holder comprises a ring structure in which at least three capsule-capture members (haptics) extend outwardly from the center of the ring (see FIG. 1). The number and size of capsule-capture members of the optic holder varies depending on the number of sections which the clinician determines to be optimal. In so determining, an optimal number of sections may be determined to be that number which will permit the greatest axial movement of the optic that can be achieved without compromising the integrity of the capsular bag. Further considerations regarding the number of sections to be made include allocating an amount of time for sectioning which the clinician feels is appropriate for the safety and well-being of the patient.

The haptics of the optic holder are made from inert or biocompatible materials known to those of skill in the art, for example, silicone, polypropylene, acrylic polymers or the like. Haptics are made in an open configuration (loops), and may be of any shape, for example, generally triangular or trapezoidal, which, as a group roughly define a disc that is coextensive with the capsular bag. Generally, the outer edge of the haptics extend to the equator of the capsular bag to form a capsule-reinforcing disc which is roughly coextensive with the capsular disc, and by virtue of their shape or porosity,

permit fusion of the anterior and posterior leaves of the capsular bag to form a capsular disc encasing the haptic.

The number and configuration of individual members are chosen in accordance with considerations discussed supra to anchor the optic-holder ring in the capsular bag and form an internal "frame" on which the fused capsular disc is supported. To maximize or minimize the diameter of capsular bag during fusion thereby impacting the ultimate size of the fused capsular disc, accommodation can be controlled during fusion of the capsular bag by administration of an agent to inhibit or induce accommodation.

Optics

The intraocular lens system of the invention may comprise multiple lens holders and therefore, be able to hold one or more optics. Optics are generally symmetrical about the optical axis. Examples of suitable optics are well known in the art and can be adapted for use with the optic holder and zonular capture haptics of the invention. These include optics that are flexible, deformable, foldable, or rigid, preformed or fillable and which are made from a liquid, solid or semi-solid material. In one embodiment, if a flexible optic is used, it can assist in accommodation not only by anterior-posterior displacement, but also by changing its radius of curvature.

Examples of suitable optic materials include silicone(s), acrylics, hydrogels and other inert or biocompatible polymers known to those of skill in the art. In one embodiment, the optic comprises a means for securing the optic into the haptic, for example a circumferential releasable connecting rib or series of releasable connecting tabs or pins that snap into a corresponding groove, notch or hole on the haptic.

Haptics may incorporate any means suitable for attaching and securing the optic; these are well known in the art.

Sectioning of capsular disc after fusion and fibrosis of the haptic therein can be accomplished by virtue of a small gauge (for example, 23 or 25 gauge) trans-conjunctival vitrectomy system with trocars and cannulas placed diametrically opposed to the section line in the capsule/haptic where the section is to be made. A small gauge (for example, 23 or 25 gauge) scissor is introduced through a cannula and used to cut the capsule from the visual axis to the outer edge of the capsular disc.

While several aspects of the present invention have been described and depicted herein, alternative aspects may be effected by those skilled in the art to accomplish the same objectives. Accordingly, it is intended by the appended claims to cover all such alternative aspects as fall within the true spirit and scope of the invention.

A haptic arrangement was manufactured from 4-0 surgical Prolene sutures with 7-0 surgical Prolene retention bands (FIG. 10). The function of the retention bands are to maintain the shape of each haptic loop, to function as an additional retaining anchor within each haptic and to maintain the distance between the haptics during the sterilization process. The surgical procedure for implantation of an optic holder of the invention consists of two stages.

All procedures related to the use of animals conform to the Guide for the Care and Use of Laboratory Animals (National Institutes of Health, National Research Council) and are approved by the Wisconsin National Primate Research Center. The animals are housed in facilities accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC). Animal subjects are paired or individually housed. Diet consists of monkey chow supplemented with fresh fruit and vegetables. Water is freely available. All animals are observed daily by a veterinary technical staff and caretakers for signs of ill health.

Adult Rhesus monkeys (*Macacca mulatta*) of either sex without any ocular disease, are the subjects of the following experiments.

At Stage 1, the treated eye is rendered aniridic by complete surgical removal of the iris. The absence of the iris facilitates evaluation of the optic holder's performance. Standard cataract removal by small, clear corneal incision and phacoemulsification is followed by implantation of the lens holder of the invention via standard 2 mm lens injector (Photo 2). The treated eye is maintained in a pharmacologic state of forced accommodation by the administration of pilocarpine drops 4 times per day. This allows the zonules to be free of tension during the healing, fibrosis, contracture phase of the capsular bag. A minimum capsular disc size is thus obtained, which is anticipated to securely incorporate the haptics of the lens holder in between the fused anterior and posterior capsules. Once the fibrosis phase is complete, approximately 2-4 weeks after the Stage 1 surgery, the animal is anesthetized again for the Stage 2 surgery.

A 23 or 25 gauge standard vitrectomy instrument is employed. Four trans-conjunctival cannulas are inserted at the standard pars plana location, coinciding with the planned capsular section lines as defined by the location of the spaces between the haptics. A central posterior capsulotomy is performed with the vitrectomy instrument. A 23 or 25 gauge Vitreoretinal scissor is introduced via each cannula to perform radial cuts extending from the edge of the posterior capsulotomy to the equator of the capsular bag, cutting across the fused capsular sheets, the 7-0 Prolene suture extending in between capsular members, to the edge of the capsular disc, ensuring that no connection remains between the individual sections of capsular disc capsule. The only connection between the sectioned capsules and entrapped haptics is the flexible inter-haptic loop extending from one haptic to the next.

Administration of pilocarpine drops is discontinued post-operatively. Once the eye has recovered from the surgical intervention, the eye is challenged with pharmacologic accommodation and relaxation of accommodation under anesthesia with short acting pharmacologic agents while the eye is monitored and videographed. It is anticipated that during relaxation of accommodation, zonular tension is produced and transmitted to the individual segments of the former capsular disc, which now move independently. Each haptic of the optic holder should move centrifugally and away from each other. When accommodation is induced pharmacologically, the tension of the zonules is released and the elasticity of the inter-haptic loops returns haptics to a closer configuration. A change in diameter of the optic holder of up to 1 mm is expected, based on previously published data.

I claim:

1. A method for improving accommodation of an intraocular lens system in an eye, the method comprising:

- (a) providing the intraocular lens system comprising a plurality of spaced radial haptics;
- (b) positioning at least a portion of the system in a capsular bag of the eye;
- (c) allowing anterior and posterior leaves of the capsular bag to fuse; and
- (d) making a plurality of substantially radial cuts in the fused anterior and posterior leaves of the capsular bag to produce sections each containing a haptic.

2. The method of claim 1, wherein the system comprises an optic and an optic holder, the method further comprising inserting the optic into the optic holder after the capsular bag has fused.

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3. The method of claim 1, wherein said intraocular lens system comprises an optic holder comprising the plurality of radial haptics.

4. The method of claim 1, wherein said plurality of haptics are regularly spaced and define sectioning intervals therebetween for the substantially radial cuts.

5. The method of claim 1, further comprising maintaining the eye in an unaccommodative state during the fusion of the capsular bag.

6. The method of claim 1, further comprising maintaining the eye in an accommodative state during the fusion of the capsular bag.

7. The method of claim 5, wherein maintaining the unaccommodative state comprises administering an agent to inhibit accommodation.

8. The method of claim 7, wherein said agent comprises atropine.

9. The method of claim 6, wherein maintaining the accommodative state comprises administering an agent to promote accommodation.

10. The method of claim 9, wherein said agent comprises pilocarpine.

11. The method of claim 1, wherein the capsular bag fuses within about 1 to about 6 weeks.

12. The method of claim 1, wherein the capsular bag fuses within about 2 to about 4 weeks.

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13. The method of claim 1, wherein said cuts extend from a visual axis to an edge of the fused capsular bag.

14. The method of claim 1, wherein the system comprises an optic and an optic holder, and wherein both the optic and the optic holder are positioned in the capsular bag prior to fusion.

15. The method of claim 1, wherein the system comprises an optic and an optic holder, the method further comprising releasably securing the optic in the optic holder.

16. The method of claim 1, wherein said plurality of haptics comprises no more than 120 haptics.

17. The method of claim 1, wherein the system further comprises a restricting device configured to maintain the haptics in a specific state of accommodation during fusion of the capsular bag.

18. The method of claim 1, wherein the system further comprises a retainer adapted to achieve a desired capsular disc size.

19. The method of claim 1, wherein the plurality of substantially radial cuts comprises a plurality of single cuts between the plurality of radial haptics.

20. The method of claim 1, wherein each haptic comprises a closed-loop structure.

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